Somaesthetic Meditation Wearable: Exploring the Effect of Targeted Warmth Technology on Meditators' Experiences

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Figure 1: The novel targeted warmth wearable designed to support the sensitive process of introspection during meditation, placed in two body locations, the belly (Left) and the right shoulder blade (Right). The warmth sensation draws attention inward and strengthens self-exploration of bodily sensations, feelings, emotions, and thoughts.

ABSTRACT

Mindfulness meditation has vast benefits, yet is challenging for many. We designed a novel targeted warmth somaesthetic wearable and evaluated how the thermal sensation is perceived during meditation. In a qualitative study, twenty participants explored the wearable during meditation. Findings reveal participants' rich experiences, sensations, and feelings. They perceived the technology as an appropriate tool for self-exploration. Even when participants initially felt the wearable was distracting their meditation process, they easily learned how to leverage it in their introspection process. We report on four potential roles for warmth technology: functional (pulling focal of attention), behavioral (motivating to "get back to the practice"), emotional (comforting during the lonely process), and therapeutic feelings. We conclude with design guidelines, highlighting that warmth is a promising technology for meditation if designed to encourage self-exploration of body sensations and emotions while not compromising the natural meditation practice.

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CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Interaction design theory, concept and paradigm.*

KEYWORDS

Introspection, Somaesthetic, Wearable, Meditation, Targeted Warmth

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1 INTRODUCTION

Mindfulness meditation has become a prevalent practice [6] with many benefits for health and well-being [4, 8, 13, 14, 17, 26, 28], specifically, for the management of stress, depression, and chronic pain [7, 58, 60].

Yet, meditation presents several challenges for many meditators, including physical discomfort, difficulties in maintaining inner focus amid distractions, low ability to gain or maintain attentional control, and the ability to regulate feelings of excitement, alertness, fear, stress, or anger [39, 50]. In addition, during meditation practice individuals may experience anxiety, drowsiness, or frustration towards the practice itself, leading to doubts about the process. Some meditators describe tension and headaches resulting from concentration efforts, as well as disruptions caused by unresolved emotions [39, 50]. Mindfulness is a skill, and like any skill, it demands practice over time, which presents many challenges including time allocation and prioritization. This is especially relevant when motivation decreases due to monotonous and wearisome feelings, leading to questioning its value altogether. These very well-known and common struggles can overshadow the positive aspects, making the practical integration of meditation into daily life very challenging [39, 50].

These challenges present a gap that is highly relevant for HCI designers and researchers, and indeed the HCI community has explored various technologies for meditation using different approaches, from mobile apps to VR experiences. In this work, we chose to focus on the design of a physical wearable technology, following the somaesthetic approach, a philosophy advocating that all of our interactions and experiences in the world occur through our bodies [25].

Somaesthetics, introduced by the philosopher Richard Shusterman, focuses on recognizing the subjective self and centering it around the body, emotions, and thoughts, coupled with our capacity to enhance our understanding of sensory experiences [23]. The somaesthetics perspective positions the body as a flexible tool that can be shaped and improved. The somaesthetics philosophy underscores the notion that improving body awareness, and optimizing our bodily abilities are as crucial as nurturing our intellectual faculties [24], and suggests that through refinement and exploration of the body, one can enhance their experience and cultivate a more effective way of existing in the world [25]. Somaesthetics therefore involves deepening aesthetic appreciation for the body's sensations, encompassing both pleasurable and unpleasurable feelings, and embracing the entire range of human experiences [23]. There are many fascinating HCI works involving the somaesthetics approach, including both design processes and user studies. Most works involve introspection in general, and some focus on meditation in particular [2, 42, 45, 59, 63].

Our motivation is to explore the potential of a novel somaesthetic wearable technology that utilizes only one modality, targeted warmth, as a tool for meditation that encourages self-exploration of bodily sensations, emotions, and feelings. Our goal is to design a technology that supports meditators during their practice, without distracting or interfering with their meditation experience, which is an individual, self-reliant, and introspective process. Meditators frequently use physical non-technological objects as support and find them to be appropriate for meditation, for example, pillows to decrease physical pain or blankets to regulate body temperature. Can technology be designed to be as appropriate as these objects?

We chose to focus on a single modality, targeted warmth, as warmth sensations were found to be perceived as internal stimulus rather than external [9], which may help achieve our goal. Additional characteristics of the warmth modality are therapeutic benefits [15, 20, 31, 51, 52, 54, 71] and a strong association with emotions [67]. Our design approach is to use meditation-appropriate materials such as fabrics and to encourage self-exploration of the warmth sensation by providing meditators with a wearable that can be strapped to various locations on the body.

We evaluate our wearable prototype in a qualitative lab study, aiming to uncover participants' rich subjective experiences, feelings, and interpretations of the warmth sensation during meditation. We discuss the various roles warmth technology can have in the context of meditation, and unfold the unavoidable tension between technology as an external stimulus and meditation as an introspection process, concluding with design guidelines that will hopefully empower HCI designers to create and study novel technologies that connect people more deeply with their body and mind.

2 RELATED WORK

Meditation has been explored in HCI context in various ways, from meta-review papers [10, 65] to prototypes, mostly involving VR experiences, some coupled with neurofeedback [33, 70] and others with physiological measurements [61]. The most relevant works to our research are somaesthetic or body-focused projects that use thermal modality in a meditation context. Other related domains are thermal interaction in a non-meditation context, multi-modality prototypes studying body awareness, and therapeutic benefits of thermal sensation in a medical context.

2.1 Body-focused Prototypes with Thermal Modality in Meditation Context

The *WarmMind* prototype [9, 57] explored embodied metaphors of Mindfulness meditation states using both warmth and audio modalities. The meditation states were defined using the EEG-based Muse band (i.e. being mindful, change of state, mind wandering), and each state was mapped to a thermal or an auditory pattern based on embodied metaphors. The thermal-related WarmMind prototype was designed as a necklace with four thermal actuators, worn on the chest and extending down towards the navel. The thermal patterns mapped to the various states were: being mindful is no movement, change of state is structured movement, and mind-wandering is agitated movement. Their study focused on comparing participants' experiences with the two modalities. Their results show that audio modality was perceived as external stimuli, while the thermal modality was perceived as internal, "as if originated from the body", and led to increased awareness towards the body.

Our work builds on and extends the WarmMind research. The similarities are wearable with thermal modality in a meditation context. However in our work, the wearable is designed as a self-exploration tool for participants to place in various body locations during meditation, and our qualitative analysis addresses a different research question, inquiring deeply into the subtle and rich interpretations meditators associate with the warmth sensation, and whether they perceive it as a disruption or an aid.

The Soma Mat and *Breathing Light* [63] leveraged the "designing for somaesthetic appreciation" process [25]. The Soma Mat prototype is a large mat designed to guide participants during body scan meditations, Feldenkrais sessions, or relaxation. The prototype guidance was implemented using a scripted process that operated different heat pulses along the mat. The heat pulse script was controlled using a mobile app with pre-recorded sessions. The Soma Mat was evaluated together with the Breathing Light prototype, a large lamp that measures one's breathing and produces ambient light above the head dimming in sync with the breathing. Results from the exploratory evaluation reported feelings of relaxation and body awareness, and the authors summarized that the work encourages exploration and somatic awareness of one's body. Another study that led to the Soma Mat design looked at thermal stimuli in body awareness exercises, reporting on felt body experiences and several design qualities related to heat as a design material [27].

Our work differs by deeply focusing on meditation and thermal modality only, and by enabling users to self-explore the warmth sensation in various locations of their body. Our qualitative analysis delves into participants' interpretations of the warmth sensation during their meditation experience, revealing the different roles warmth sensation can have in meditation. In addition, we critically examine the tension between meditation and technology.

2.2 Prototypes with Thermal Modality in Non-meditation Context

Thermal interaction was studied in various HCI contexts, including music, perception of voice and text messages, VR experiences, remote presentations, parent-child interaction, and navigation.

In music context, *ThermOn* [1] prototype produced thermal sensations in the ears using headphones, reporting on changing users' impression of the music and altering users' attention towards it.

In the messaging context, the *ThermalWear* [11] on-chest wearable prototype, showed that thermal sensation can affect the perception of neutrally spoken voice messages, with warm stimuli increasing valence and cool stimuli decreasing it. *"The Heat is On"* [66] wearable prototype, showed that thermal stimulators on the wrist and forearm enhanced emotional reactions to text messages, especially those that are emotionally neutral. Kim et al., [32] investigated thermal interaction with a voice-based intelligent agent, reporting on thermal interactions to increase understanding of information, enhance the agent's sense of presence, and create an immersive and engaging experience. Thermal feedback was found to increase or decrease feelings of immersion also in the VR context, depending on its congruency with the visual scene, as was evident in the *ThermoQuest* [56] prototype.

Thermal feedback was also studied in emotional and attentional contexts. A thermal wristband that was designed to communicate a group's states in a distance presentation context, was found to increase feelings of connectedness, while not being distracting for the presenter [21]. The *TouchMe* prototype [37] is a heart-shaped wearable bracelet designed for parent-child interaction with thermal modality as ambiguous feedback. Parents used the device to express feelings of affection or to convey non-emotional information, while the thermal sensation was openly interpreted by children, leading to creative meaning-making.

In the navigation context, *ThermalCane* [46] used thermal cues to convey navigation information, yielding higher accuracy with blind and visually impaired people, in comparison to vibrotactile feedback. In addition, the *HeatNav* [66] prototype demonstrated how warm temperatures are effective in informing participants with navigation cues.

These prior works, implement the thermal modality in non-meditation contexts. We build on these prior works by utilizing thermal modality in the specific context of meditation.

2.3 Multi-Modality Prototypes Studying Body-Awareness in Various Contexts

SWARM [72] is a cotton scarf with conductive fabric circuitry aimed at aiding users in understanding and managing their emotions and interpreting others' emotional states. Each emotion (stressed, sad, calm, happy, and excited) was associated with a distinct multi-modality pattern that includes vibration, music, weight, light, and thermal. Thermal emerged as one of the favorable modalities for emotional detection and alerting. *Haplós* [42] is a garment shaped like a corset, providing vibrotactile patterns to the wearer. Participants interacted with the wearable in a workshop that included Feldenkrais and mindfulness techniques. The vibrotactile patterns were found to increase bodily sensation and awareness. Aslan et al. [2] presented two physical prototypes, an anatomical heart-like artifact allowing users to physically sense their heart's pulses, and a stuffed animal capable of synchronized breathing with the user. The prototypes were evaluated in a workshop with experts in mindfulness-based stress reduction (MBSR) meditation. Findings suggest the potential of a somaesthetic approach to increase trust and engagement but raised concerns about directing users' awareness externally rather than internally, away from internal processes and towards the external artifact.

These prior works validated the potential thermal modality has in directing awareness inward, towards the body, rather than outward and away from the body towards external modalities.

2.4 Therapeutic Benefits of Thermal Sensation in Western and Eastern Medical Context

Thermal sensations in medical use are documented already in Roman Empire times and were extensively studied in Western medicine [20]. Findings show health benefits of exposure to warmth (e.g., sauna baths, hot water immersion, infrared bathing, and steam bathing [15, 52]), as well as the effect of targeted warmth in various body locations (e.g., solely on the feet [51], lower back [16, 43], or quadriceps muscles [18]). Some studies found specific health benefits, from enhanced muscle strength [31], improved quality of sleep [51], reduced blood pressure [54], enhancement of cardiovascular health [54], and decrease in inflammation processes during recovery [15].

In Eastern medicine, thermal sensation has long been associated with health benefits. Moxibustion therapy (Moxa), a specific treatment that originated in Japanese tradition is based on the burning of mugwort leaves near the skin, and hence applying targeted heat to a patient's body[5, 48]. Academic studies of Moxa treatment were found to be beneficial in managing pain related to chronic diseases [36], pain reduction related to autoimmune diseases [74], enhance

blood flow in the tendons [34], to help regulate the level of sexual hormones [62], or alleviate menstrual pain-related symptoms [62, 73].

Such works enhanced our motivation that targeted warmth during meditation may be perceived as beneficial for muscle pain that is common during meditation. It is important to highlight that in this work we aimed to explore the subjective perception of participants towards the targeted warmth, and not to evaluate any actual effects on participant's health.

In sum, prior work shows promise of thermal modality in meditation context, by being perceived as an internal stimulus, by affecting valence and emotions, and by directing attention and conveying information. We build on prior work and extend it, by designing a wearable technology that utilizes targeted warmth as a single modality and promoting self-exploration of various body sensations.

3 DESIGN AND IMPLEMENTATION

Our design process started with a literature review of somaesthetic design, identifying design principles relevant to our goal. We then started the technical implementation, followed by a series of pilot studies, from a need-finding study about relevant body locations to prototype testing including both low-fidelity and high-fidelity prototypes. This process led to the final design of the somaesthetic warmth-producing wearable.

3.1 Somaesthetic Design Principles

When designing for somaesthetic experiences, Höök et al., [25] described the experiential quality called *"Turning Inwards"*. This quality involves a shift of attention inward while not disconnecting from the external world. The concept of "turning inward" is guiding somaesthetic design processes, helping to make decisions and choices for interactions that embody this experiential quality.

Another relevant term is *"Somaesthetic Appreciation Design"*, encouraging designers to consider several concepts and dimensions during their design process, including modalities, timing, the intensity of the feedback, and aesthetics [25]. Below we detail each principle and explain how we applied it in our design process. **(1) Modalities**: choose a sensory channel that supports internal exploration. We applied this principle by choosing thermal stimuli as our technology's only digital feedback stimuli. Our choice is grounded in prior work, specifically studies that found thermal stimuli to be intimate, soothing, and promoting heightened bodily awareness [25, 63], as well as being perceived internally rather than externally [9, 57]; **(2) Timing**: the system needs to smoothly match with the user's focus on a somatic aspect, and not arrive before or after the event. We applied this principle by designing a wearable for self-exploration, utilizing a strap that allows users to place the warmth sensation on their preferred body location during meditation, matching the warmth sensation to the user's desired bodily focus; **(3) Intensity**: the somaesthetic effect should be applied subtly, gradually getting stronger, and then slowly fading instead of stopping or appearing suddenly. We applied this principle by designing a thermal pattern using Arduino, with the warmth gradually increasing and decreasing. **(4) Aesthetics**: promote aesthetics appreciation. We applied this principle by designing with fabrics, and soft materials that are appropriate for meditation.

3.2 Technical Implementation

With the choice of thermal sensation as the main modality, we started to explore different thermal technologies. We tested Peltier, conductive threads, and Polyimide heater pads. The Peltier device was very durable, but rigid, making it inappropriate for a soft wearable. The conductive threads had low heat stability and required a relatively high operating voltage. The Polyamide heater pads were the most suitable. These pads are thin, lightweight, and flexible. They come in different shapes and sizes and are widely used in electronics manufacturing, medical devices, and scientific instruments. They require low voltage (6V), are safe to use, and provide stable performance.

To define the desired temperature we performed several cycles of testing. We did not test the Polyimide heater pads directly on the skin, as we wanted participants to place them over their clothing items. Also, when integrated into the wearable unit's fabric, the heater pad was placed 1.2mm below the fabric's surface, so the heat was transferred through the air between the heater pad and the clothing item. Based on the somaesthetic principle of "intensity", thermal perception studies [22, 68, 69], and to avoid thermal habituation [68, 69], we adopted the approach of a thermal pattern that gradually progresses from low heat to higher heat and back, rather than a fixed temperature. We explored different temperature ranges over clothing items in various locations of the body (belly, chest, back), mapping when the warmth was noticeable and pleasant, and when it was starting to feel too warm. The result was a temperature range of 38-42 degrees Celsius, measured using a dedicated temperature measurement tool.

The hardware implementation included an Arduino Uno R3 board, a MOSFET Power Controller, and a power bank of 5,500 mAh 5.0V (see figure 2). The Polyimide heater pad specs are metal foil covered with polyimide film, 50mm diameter, 3.7V-5V voltage, 3.7 ohms resistance, and a total range of temperature 35-55 degrees Celsius.

To implement the thermal pattern we used a very simple technique, setting a MOSFET element to On for 10 seconds to gradually heat the pad, then setting it to Off for 15 seconds to gradually cool the pad, so the interval between the MOSFET On and MOSFET Off created the effect of a thermal pattern. We used a 5,500 mAh power bank to power the heater pad directly using the MOSFET element, which served as an excellent safety measure, as a 5,500 mAh current produced a maximum heat of 42 degrees Celsius

3.3 Iterative Design Process

In parallel to the technical implementation, we conducted a need-finding study and a series of prototype testing pilots, to explore the form, materials, and body attachment mechanism.

In the need-finding pilot study, we asked five participants (with varying experience in meditation) to perform a standard 10-minute meditation session, followed by an interview about their awareness of various body locations. The findings highlighted awareness of the body's head, chest, and palms, and comments about body

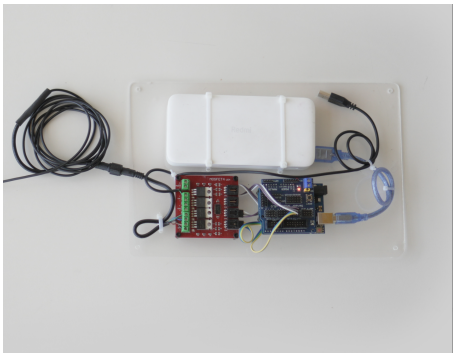

Figure 2: The hardware: Arduino Uno R3 board, a MOSFET Power Controller, and a power bank of 5,500 mAh 5.0V.

discomfort in the back, shoulder blades, and thighs. Interestingly, participants described the movement in their descriptions, focusing on numerous points on the body, mostly on axes (upper chest to abdomen, one hand to the other, upper back to lower back, etc.).

We continued with exploring various low-fidelity wearable designs, evaluating how participants place them on their bodies. We designed various shapes from felt fabric (two circulars, a back "U" shape belt, and a chest "I" shape belt. See figure 3) and tested them with 4 participants in short design pilots, evaluating the affordances of the designs and their relevancy for the body areas identified in the previous pilot. We learned that participants desire more flexibility in exploring various body locations and that the circular shapes were the most appropriate.

Figure 3: Pilot study exploring low-fidelity designs and possible body placement

We continued our design exploration on two axes, one with designs that touch the body in two body parts, to match the feeling of movement described in the pilot, and one with a single touchpoint, to increase the need for explorations of various body placements also described in the pilot (see figure 4 of the different design paths). We tested the next design iteration with three participants who used it during meditation, the specific designs were a scarf made of foam sheet and a glove made of fabric. The meditators appreciated the multiple attachment options of the scarf form but were confused by the two heating points on their body. They also mentioned that it was too cumbersome. The glove design turned out to be more convenient for exploration, meditators stated it was hard to constantly hold their hands at the desired body location, and it should be effortlessly attached to the body.

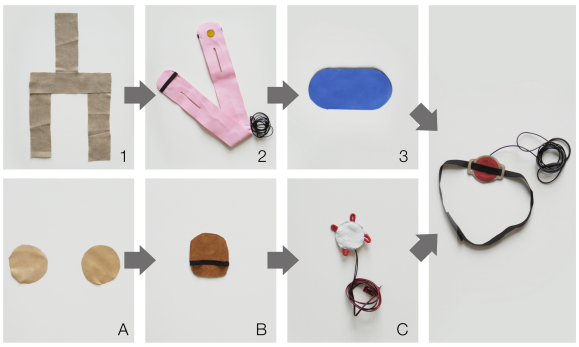

Figure 4: Pictures of the design process and the two exploration paths of low-fidelity prototypes that eventually were consolidated into the final high-fidelity prototype. 1: The U-shape belt; A: Two circular fabrics; 2: Scarf made of foam sheet; B: Glove; 3: big pocket; C: small pocket

The main insights from this stage were the need to support easy placement on a variety of body parts without the need to hold the device, and making sure the attachment to the body is firm so the thermal sensation is evident on the body. We continued with testing different body attachment mechanisms for fastening the wearable unit to the body, testing variations of ropes and bands, including Samson rope, nylon bands, and elastic bands.

Following the insights from the design pilots, we designed the final prototype. We used a small round red fabric (60 mm diameter) as the wearable main unit. The body-facing side had a circular cut-out (40 mm diameter) for the Polyimide heater pad to be mounted 1.2 mm deeper into the circular fabric, to enable heat transfer while preventing direct touch to the body or a clothing item. The externally-facing circular part was fully covered with fabric. The circular unit had two slots on the edges, for the fastening elastic band to pass through. The elastic band created just-enough pressure, allowing the warmth to be felt when placed on top of a clothing item (see figure 5 for the final prototype, without the Arduino unit).

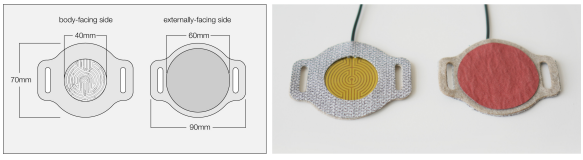

Figure 5: The targeted warmth wearable: the body-facing side with the 40mm diameter heater pad mounted 1.2mm below the grey fabric's surface, and the externally-facing side with a 60mm diameter red fabric layer covering the back of the heater pad.

3.4 Safety and Health Consultation with Eastern Medicine Expert

The design process was led by experienced meditators (the authors) from a Buddhist meditation perspective. When the warmth sensation was implemented in the prototype and was felt on the body, we invited an Eastern medicine expert with specific expertise in thermal therapy to understand the potential risks and to fine-tune the heat intensity design. The expert has had his private practice for many years. His expertise includes Chinese and Japanese alternative medicine, specifically Moxa treatment. Moxa is a traditional Japanese therapy involving heat created by burning of dried mugwort leaves near the skin to stimulate acupuncture points, promoting circulation and natural healing. Moxa is used to address various health issues and is often combined with acupuncture [5]. We asked the expert to test our prototype on his body, assessing the min and max warmth levels. He concluded that the max thermal sensation is far from reaching unhealthy levels and that based on his experience treating people for many years, our range is safe. In addition, we asked if there was any risk related to specific body locations. He recommended starting with the lower abdomen or lower back, that all body parts are safe for such temperatures, that the lower abdomen or lower back are most relevant in his perspective, and that the only body part he does not recommend placing any heat on is the heart. We adopted his recommendations and added them to the study procedure.

4 METHOD

Meditation, as well as somaesthetic experiences, are highly subjective experiences. Our research goal was to leverage qualitative analysis to uncover participants' feelings, sensations, emotions, and preferences regarding the targeted warmth-producing wearable, so we can better understand its effect during the specific context of meditation. We considered two interview methodologies that were previously used in meditation-related experiences: micro-phenomenology (MP) interview [53] or the more standard semi-structured qualitative interview [44]. To decide between the two we conducted a pilot study with five participants with varied experience in meditation, and evaluated participants' ability to share their meditation experiences with either of the interview methodologies, alternating after each participant. The micro-phenomenological interviews started with "Please share the experience you just had", followed by participants' experiences about being mindful or distracted. This methodology highlights asking follow-up questions that direct participants towards a singular experience, i.e., a specific moment with its specific sensations and feelings. In the case of our pilot study, the exploration uncovered profound descriptions of bodily sensations during specific moments in the meditation session. However, these insights were too specific to one sensation, and prevented us from uncovering the comprehensive experience and its development along the meditation process, with various moments, experiences, sensations, and feelings throughout the 10-minute meditation session. We learned that the qualitative interview technique was more appropriate in helping participants verbalize their thoughts, emotions, and feelings over the entire meditation process. In addition, we saw that during the interviews, questions adapted from the State Mindfulness Scale (SMS) [64] were effective as guided reflection, helping participants reflect on various aspects of their meditation experiences, for example, awareness of changes in body postures and awareness of various body sensations. We, therefore, focused on a standard semi-structured qualitative interview and included some questions adapted from the SMS questionnaire as a guided reflection between the meditation sessions and the end of the study during the post-experience interview. The study received IRB approval from the university's ethics committee.

4.1 Participants

20 individuals participated in the study (10 females and 10 men; 24-59 years old, mean age=32, SD=9.4). All participants were native speakers of the country's language. The participants' experience in meditation varied from inexperienced (0-1 year, N=9) to experienced (4 years and above, N=11). The range of expertise allowed us to explore the perception of the wearable by both novices and experienced meditators.

4.2 Experimental Design and Measures

To enhance the potential for self-reflection about the targeted warmth sensation during meditation, we designed an exploratory study with two short meditation sessions, one with the wearable and one without, hoping that the different experiences would make it easier for participants to verbalize their introspective process. Each participant had a warm-up session, then meditated once with the wearable and once without. In between the sessions, we held a very short reflection session, and at the end a long qualitative interview. To try to minimize the influences of the research environment on the meditation experience, we made sure to create a distraction-free environment by using a quiet room, soft lights, and minimal noises. We also made sure that the environment would feel more appropriate for meditation, as close as possible to a home meditation area or a retreat center with meditation pillows and a warm home-style carpet. Additionally, when participants entered the quiet research room, they were asked to read a short emotionally neutral text to distance themselves from daily activities and the external lab environment outside the room.

- 10-minute warm-up session: All participants engaged in a 10-minute non-meditation reading session to feel more comfortable in the study environment and "ease into" the upcoming meditation sessions.
- 10-minute meditation session: half of the participants meditated with the wearable and half without.
- 2-4 minutes reflection sessions: to enhance the potential for self-reflection during such a subjective experience, all participants were asked one open-ended question that was not followed-up (*"please share shortly about the experience you just had"*), and reviewed several written sentences regarding meditation in general as guided reflection (the sentences were adapted from the State Mindfulness Scale (SMS) questionnaire [64]: *"I noticed pleasant or unpleasant thoughts", "I change my body posture and paid attention to the physical process of moving"*, etc. Participants read the same sentences as guided reflection also in the post-experience interview.

- 10-minute meditation session: second meditation session, half of the participants meditated with the wearable and half without.
- 15-20 minutes: a post-experience qualitative interview, with several questions and long follow-ups based on the natural dynamics of the discussion, asking participants to reflect on the experience with the wearable (either first or second meditation session), discussing their feelings, emotions, thoughts, focal of attention, and overall preferences regarding the warmth sensation on their body, preferred body locations, the wearable design, and their opinion on the broader concept of technology for meditation.

4.3 Procedure

Once a participant arrived in the lab, they completed a demographic questionnaire that included their age, gender, and years of experience in meditation. The researcher explained that the study involves a new technology for meditation, and that they would engage with a safe prototype that produces low heat. The participant signed a consent form and was invited to enter the quiet experiment room that included a chair, desk, laptop, a meditation rug, a meditation sitting pillow, and two optional meditation-supporting pillows for the legs. (See figure 6 for the experimental setting)

Participants were invited to start the "warm-up" session by sitting on a chair in front of a desk with a laptop and reading an emotionally neutral article on a new animal that was brought to the local zoo. This stage aimed to form a transition from the fast-paced of everyday life to a slower and more quiet atmosphere before starting a meditation session. The researcher then invited the participant to sit on the floor in the meditation area and start the meditation process, either with or without the wearable.

If the wearable was included, they were introduced to the wearable, were instructed to place it on top of their clothes and not directly on the skin, were informed they could change its location or remove it completely at any time, and were asked to feel the temperature and approve if it feels ok or if they want to change it. During the study, none of the participants were asked to reduce the temperature, and none removed the wearable during their session. They were informed that an expert recommended to start placing it on the lower abdomen or the back, but that it is completely up to them and they can place it anywhere they wish except the heart area, that they can change the location during the session, and can also remove it completely.

Then, a short definition of mindfulness meditation was presented, no matter what the level of experience of the participant was: *"The state of mindfulness is characterized by attentive and nonjudgmental metacognitive monitoring of moment-by-moment cognition, emotion, perception, and sensation without fixation on thoughts of past and future"* [17].

Next, the researcher presented the meditation instructions, in the same way reported by [19]: *"I invite you to sit still with your eyes closed and focus your attention on different qualities of the present moment, for example, sounds, smells, body sensations and the breath. When you notice that your attention has wandered off from the present, please observe the focal point of your attention without judgment or reaction, and then bring your attention gently back to the present moment"*. There are many Meditation techniques and styles, some guided and some unguided, some highlighting practice on focused attention [40], and others highlighting open monitoring, loving-kindness, or compassion [41]. To support participants with low experience in meditation, while not limiting participants with experience in a specific technique, we chose to introduce the meditation practice in a "minimal guidance" style, commonly used in mindfulness practices, that broadly presents meditation. This choice of minimal guidance also aided in minimizing bias that may occur due to participants' wish to please our expectations for a specific type of meditation or specific experiences during meditation. We therefore used the instructions listed above that were also previously used in meditation research [19].

Then, the participant started their 10-minute meditation. The researcher stayed at the back of the room during the meditation sessions. For the one with the wearable, it was in case any concerns would be raised regarding the wearable, and in the session without the wearable, it was for keeping both experiences as equal as possible. After 10 minutes, the short reflection session was performed, followed by the second 10-minute meditation session. Then, the final interviews took place. At the end of the interview, the researcher debriefed the participant and verified that the experience was positive overall.

Figure 6: The experimental setting was a quiet room with a meditation rug, meditation sitting pillow, two optional supporting pillows for the legs, and the targeted warmth wearable.

4.4 Qualitative Analysis

The qualitative analysis of the interviews allowed us to uncover the rich subjective experiences, sensations, feelings, and preferences participants had with the somaesthetic warmth-producing wearable during their meditation session. Two coders and a senior researcher used the thematic coding process to analyze the data [3]. The process included five steps: (1) The recorded interviews were transcribed, then two coders reviewed three interviews several times to gain a general understanding of the data; (2) Each coder identified initial themes individually, and then presented and discussed with a senior researcher, inconsistencies were analyzed and resolved; (3) A list of initial themes was defined; (4) The two

coders continued to individually analyze half of the data (10 interviews), comparing the themes and resolving inconsistencies, until a satisfactory level of agreement was reached (Cohen's kappa= 88%); (5) Then, the remaining interviews were analyzed according to the final list of themes.

5 FINDINGS

The qualitative analysis of participants' interviews revealed four high-level themes: interpretations of the warmth sensation, the tension between self-reliance and technology-supported process, feelings regarding body placement, and wearable design aspects.

5.1 Theme 1: Interpretations of the Warmth Sensation

Participants' subjective interpretations of the warmth sensation were surprisingly rich and meaningful, the analysis revealed four sub-themes: *grounding attention; providing companionship and support; soothing and comforting; and therapeutic feeling*. Based on the frequency of interpretations, we classified each participant into their most dominant sub-theme. Clearly, some participants had quotes that can be associated with more than one sub-theme, but with all participants a clear leading sub-theme was evident.

5.1.1 Grounding Attention (9/20). All participants in this sub-theme described the warmth sensation as an internal force that was "pulling" or "guiding" their attention inward towards the body location of the wearable. Most of them characterized it as a positive aspect of their meditation process, mentioning it helped in diverting attention away from distracting thoughts, helping them to connect with their bodies, or shifting attention away from painful areas. *"It is really present in the body and specifically in the organ that you place it on. It is much like pain, but not in the bad sense because it feels pleasant."* (p.5, years of experience (YOE)=6); *"My attention was focused on exploring the experience, it did not wander...I was focused on where the warmth was and what it made me feel or think."* (p.18, YOE=5); *"When the warmth was on my left side, my attention was drawn to the left side of my body. I had prior physical pain on my right side, but I didn't feel it anymore, not as much as before."* (p.10, YOE=5); *"There were moments in which it helped me focus my attention on my body. Suddenly feeling this warmth sensation connected me to myself, and helped me gain serenity."* (p.4, YOE=5).

Some participants felt the dominance of the warmth was too strong, taking away their freedom to direct attention elsewhere: *"I felt it was a reduction of the experience. In the meditation process I go through, the more you get into the meditation the more you open yourself to more experiences...and once you can hold the entire experience as a whole you do not need to anchor only on physical aspects anymore. The warmth drew my attention to this sole aspect when I was already used to going from one experience to the other in my meditations… But maybe when located in a different body location or when I experience anxiety it can be really helpful because it grounded me...and when I placed it on the chest it was really meaningful"* (p.15, YOE=7); *"It drew my attention to an unfamiliar experience in my body, I mean, I suddenly started to feel this warmth and noticed the pattern goes up and down, so even when I feel it calming down I know it will soon go up and I was preparing myself for this... it directed my concentration to this aspect"* (p.2, YOE=0). After some more exploration during the session, participants reported that they learned how to practice with it, and it became helpful in dealing with challenges they want to deal with: *"At the start, it was too hot and it annoyed me. It interrupted my process of getting into the meditation. But then, I placed it somewhere else and it calmed down, and another issue emerged, I'm not sure how to characterize it but it involved self-criticism. I asked myself why I had not placed it in another location before, and then I almost didn't feel it at all so I thought maybe I moved it to the wrong place or placed it incorrectly. It woke me to my own known self-criticism"* (p.3, YOE=4).

5.1.2 Supporting and Motivating (4/20). Participants in this sub-theme described the warmth sensation as a gentle, reassuring presence that metaphorically supports, motivates, and accompanies them during the lonely and unstructured meditation process. *"It feels like you are not alone in this, that there is someone with you who protects you and holds you."* (p.14, YOE=1); *"It feels like it is there for support, much like a hand that holds me. Sitting on the ground is hard, this is something that motivates me to continue the practice."* (p.1, YOE=5).

5.1.3 Soothing and Comforting (3/20). Participants in this sub-theme characterized the warmth as providing emotional comfort, as if the warmth was produced by human touch. *"It was a type of tender and loving warmth, much like a baby being put in the crib and being cradled until they could fall asleep."* (p.20, YOE=0.5); *"It was a very pleasant touch, maybe like a hug, there is something very comforting in it, much like someone close to you lays their hands on you".* (p.9, YOE=0); *"The first thing I thought of was a hug, such a hug of acceptance, I am a very defensive person and I always keep my walls up, and maybe in that moment, there was something that took it off me, some type of a hug."* (p.7, YOE=0).

5.1.4 Therapeutic Feelings (4/20). Participants in this sub-theme associated the targeted warmth with therapeutic feelings, mostly related to muscle pain or to specific organs in which they had a known pain for a while. *"I automatically placed the warmth on my lower abdomen, I have a medical condition there, and the warmth was therapeutic, it was completely healing in my experience"* (p.10, YOE=6); *"I felt like it expanded my blood vessels, making everything a bit calmer, it was very healing."* (p.19, YOE=4); *"I was able to get to the mental places I wanted to be in because it eliminated the pains I had before"* (p.17, YOE=0).

5.2 Theme 2: The Tension between Self-reliance and Technology-supported Process

Many participants wanted to discuss the tension between meditation as a self-managed internal process, and technology as an external process that may compromise the process of introspection.

On one hand, all participants felt comfortable with the somesthetic wearable as a tool that supports their self-exploration process during meditation: *"This* (the warmth sensation) *was more like a tool to me, just like one can focus on the breath or body scan, one can focus on this."* (p.5, YOE= 6); *"Warmth is interesting to explore, just as any other explorative "object". In the warmth there are several elements, the danger, the fear, but also the soothing aspect like a comforting blanket, there is a strong emotional aspect in warmth."* (p.18, YOE=5);

On the other hand, participants discussed the tension between external technological aid and the notion of meditation as a self-reliant endeavor, revealing how they learned to work with it and gradually accepted it as an appropriate support. Some mentioned how aids, in general, are counterproductive: *"I feel like a lot of the time the "aids" are a distraction, creating a positive reinforcement that in the end is damaging my ability to connect to myself to the fullest."* (p.4, YOE=5). Others emphasized that challenges are an integral aspect of a self-reliant process like meditation: *"It's hard to meditate, but it is hard because this is how it should be. I'm not sure we should make it easier by adding technology... if a technological object will make us passive it is problematic. So if we are to add technology it should not replace the hard work in the process...in this case - I did not feel that I had become passive"* (p.6, YOE=7).

Some addressed this tension by acknowledging that technology can be a supporting aid for meditation, but should be a transitory aid rather than permanent: *"In my opinion, at the moment that one can hold the entire experience, I don't see how technology can fit here, maybe, in the beginning, it can help."* (p.15, YOE=7); *"I would like to continue to explore it, but do I want to practice only with it forever? Probably not"* (p.19, YOE=4).

However, others explained how they see a value in using it also over time, as it invites new explorations: *"I experienced lots of curiosity, and I was eager to discuss it. Even when some of the experiences were familiar to me it was still different because it revolved around the warmth. The opportunity to keep exploring it in the future is very intriguing"* (p.10, YOE=5).

5.3 Theme 3: Feelings Regarding Body Placement

Most of the participants (16/20) associated the wearable position on their body with their meditation goal, for example forehead for a mind-focused meditation, the stomach for a body-focused meditation, or other locations with pain for therapeutic purposes. Chest (not on the heart) and back locations were mentioned as providing support (either emotional or physical). *"If I could, I would like to place it on my forehead, like a third eye. My initial instincts are to take this instrument for focusing and clearing the mind."* (p.7, YOE=0); *"I think that placing it on the stomach can provide a whole different experience. Feelings are in the stomach, vulnerability is in the stomach... It can also be interesting to think about the heart, especially in compassion or gratitude types of meditation."* (p.18, YOE=5).

5.4 Theme 4: Wearable Design Aspects

Participants in this theme commented about the wearable belt design and the warmth characteristics, specifically control over the temperature, pattern, and spread. The belt was designed to allow flexibility in attaching the wearable to different body locations, some found it useful *"The belt was very nice, and the fact that I could move the heat circle on the X-axis to explore different body locations was great"* (p.10, YOE=5). While others had concerns *"The belt felt tight, it was a little too tight on the body... I would like the object to be without the belt, the tightness was disturbing to me."* (p.12, YOE=5) or expected greater flexibility *"I would like to have the option to place it easily on different body locations and to easily move it from one place to the other."* (p.12, YOE=5).

Table 1: Participants' experience levels in meditation

Years of experience (YOE)	Participant number	Age	Gender
0	2	28	M
0	7	48	M
0	9	27	F
0	13	26	F
0	16	28	M
0	17	28	M
0.5	8	29	F
0.5	20	59	M
1	14	27	M
4	3	27	F
4	19	30	F
5	1	27	F
5	4	27	M
5	10	28	F
5	11	30	F
5	12	52	M
5	18	29	F
6	5	25	F
7	6	34	M
7	15	32	M

The heat characteristics were designed (based on pilot studies) with a specific pattern and min/max temperatures, some of the participants expressed a desire to control both temperature and pattern. *"Maybe it should be more random, or correlate with the pulse or something, and also have the option to self-regulate it because not every level of heat is suitable for every situation"* (p.2, YOE=0). The spread of the warmth was designed to be a few centimeters in radius, some expressed they wanted it to be broader *"I wanted the heat to wrap around me, to hold me, to be all over the belt, not focus only on one area"* (p.10, YOE=5); *"If it was like a blanket or a vest, something that can immerse you in the experience it would be nice."* (p.19, YOE=4). No comments were voiced regarding the need to make the warmth more focused than it was.

Some participants mentioned the visibility of the technology that powered the wearable (an Arduino and power bank were wired to the wearable, and placed on the floor beside the meditator, in a visible way) *"I would have hidden the Arduino to make it look like a wearable that is not technological."* (p.8, YOE=0.5, and p.5, YOE=6).

6 DISCUSSION

Meditation practice is a highly subjective, introspective experience. There are different types of meditation, with different techniques and goals, but a core aspect of all is the observation of mental and bodily sensations as they are. Meditation is also an extremely self-reliant process, emphasizing self-discipline and practice over time to improve one's ability to observe and accept mental and bodily sensations as they are. Therefore, technology designed to support meditation may contradict the essence of meditation and may create tension between a meditator's aim to be self-reliant and the technology's aim to assist. On the other hand, meditators have no objection to using tools or non-technological objects that

assist by alleviating body pain during meditation (such as pillows or small benches) or listening to meditation guidance streamed while meditating to motivate and assist in the overall meditation session.

We suggest that targeted warmth, designed as a wearable device that enables self-exploration of various bodily locations, can be an appropriate technology for meditation by enhancing one's ability to explore mental and body sensations using the targeted warmth, while not compromising the self-reliant aspects of meditation.

In this work, we presented a somaesthetic targeted warmth wearable. Our study participants used the wearable during a minimally-guided meditation session, placing the warmth sensation on various body locations and exploring the effect it may have on their sensations, feelings, and emotions. Our qualitative findings validated that warmth is a relevant modality for meditation processes. Participants with different levels of experience in meditation shared how they used the warmth in various ways, exploring their focal of attention, their awareness towards certain body locations, leveraging it to ease pain, or to induce feelings of comfort and intimacy. As one participant mentioned: *"I started to feel my whole body getting warmer, which is an unknown feeling, but it was interesting...It was like the warmth was spreading out of me. The sensation was from the inside out, from the place where the object was located outside, and back to me for more exploration"* (p.1, YOE=5); Some participants shared they felt challenged by the technology, felt it was distracting their attention, or too warm at times, or the belt was too tight, However, they also shared that after little more exploration, they learned how to work with the technology during the meditation process, by changing body placement, using it to direct attention towards body locations less explored before, or dealing with the slight rising of fear when the temperature starts to change. *"At some point, I was scared it was going to be too hot, it captured my attention and was distracting. But then I thought of it as another type of meditation, a type in which you work with unpleasant sensations. I don't have experience in these types of meditations but I know they exist. And in that moment I realized I could work with these feelings. I thought to myself here is this element that is not harmful, but it is also not pleasant, and you should keep going. It's all good. And in that context, I found it* (the object) *to be really helpful"* (p.6, YOE=7).

6.1 The Potential Roles of Warmth in Meditation

Our research revealed four sub-themes that can greatly serve HCI designers interested in the effect warmth has on introspection: grounding attention, supporting and motivating, soothing and comforting, and therapeutic feeling. For each sub-theme we present the role it serves coupled with supporting quotes, contextualize our findings in prior work, and suggest impact for HCI designers beyond meditation.

6.1.1 Grounding Attention. The grounding attention sub-theme has a functional role, as it directly influences the focal of attention, "pulling" one's attention towards the location of the targeted warmth, especially when the temperature pattern is increasing. *"I usually focus on the upper body and have these feelings of soaring high, or turning in circles, spiral feelings, and lots of 'air'. Placing this object on my lower abdomen created a different, unfamiliar meditation experience, a feeling of 'ground', focused on my lower body...It was like a pit in my stomach that everything was drawn to"* (p.1, YOE=5). These findings are in line with prior work [9, 57] that showed warmth can increase awareness of a specific heating pattern during meditation by pulling one's attention towards a predefined body location. Our findings contribute by showing that even without a predefined location or goal when users are asked to self-explore various body locations and appropriate the warmth to their meditation process in any way they wish, the warmth serves the essence of the meditation practice - directing one's attention towards various bodily sensations to explore various mental states or emotions.

The impact for HCI designers in the context of meditation is that targeted warmth technology is appropriate for meditation and can support meditators to divert their focus of attention, either away from disturbing thoughts or painful body locations, or with more advanced meditators, towards less explored body locations. Our findings may also be relevant to other contexts beyond meditation, in domains that require a shift of attention, such as the thermal navigation implemented in a walking stick for the visually impaired [46]. Potential future directions may be a targeted warmth wearable for children or students to help direct focal attention back to the task at hand and away from wandering thoughts. Another possible direction is in the gaming context, a wearable game controller that provides feedback using targeted warmth attracts a gamer's attention towards a specific event. Such directions should be studied in future work.

6.1.2 Supporting and Motivating. The supporting and motivating sub-theme has a behavioral role, as meditation is an unstructured introspection process, and the warmth helps people feel as if another human entity is motivating them and "holding" them. For example: *"I kind of felt that if it weren't for the object I would probably fall asleep or give up. It was like the object provided this gentle push saying 'pay attention, do not fall asleep, do not give up, I'm still here"* (p.19, YOE=4). This finding is in line with prior work in a non-meditation context that demonstrated how temperature changes on a wrist-based device informed participants if they were on the right path or not when following a 2D maze [66].

Our work contributes by showing that targeted warmth sensations communicate more than information, they have an integral behavioral aspect that in certain contexts can be perceived as meaningful support or motivation that helps participants keep on trying to find their path. In the context of introspection and body awareness practices, HCI designers can leverage this to increase motivation and support in challenging situations, for example when practicing Yoga or Tai Chi, many practitioners may feel overwhelmed, exhausted, bored, or incompetent, and the targeted warmth may provide a "gentle push", motivating and supporting the practitioner to not give up and continue.

6.1.3 Soothing and Comforting. This sub-theme relates to the emotional role of the targeted warmth, providing a feeling of a "soothing loving entity" in the lonely process of meditation. Participants described the warmth sensation as providing a sense of human touch, intimacy, and love. For example: *"We always speak about love as warmth, and the warmth provided gave me this sense of pleasure and love in the body"* (p.13, YOE=0). This finding is in line with prior work in a non-meditation context, for example, a somaesthetic work showing parents used the thermal modality to convey feelings of

affection to their children [37], or psychology research showing warmth-related words are correlated with positive emotions [67].

Our findings contributed by contextualizing prior work to the context of meditation, showing that abstract warmth was perceived by individuals as affection that is produced by loved ones, or produced internally in their body. Interestingly, this sub-theme was associated with novice practitioners more than experienced ones. Within the context of meditation, HCI designers can leverage this "soothing and comforting" role of targeted warmth to increase feelings of human intimacy, for example, a wearable designed for specific body parts that are common for a human's comforting touch, such as a gentle hand pat on the upper back or the neck. In a non-meditation context, the warmth "soothing and comforting" role can be used to alleviate loneliness, for example, a children's pillow can be designed to "hug back" using warmth, alleviating loneliness before falling asleep.

6.1.4 Therapeutic Feelings. The fourth role of the targeted warmth was in line with some of the non-meditation works in the medical field, ones that associated heat with soothing muscle pain and other health benefits [15, 20, 31, 51, 52, 54, 71]. In the context of our work, the ability to explore various body locations by strapping the wearable encouraged participants to explore various physical pains, including muscles, organs, and joints. For example, *"I moved the object on the X-axis of the strap and felt the warmth like a snake that moved around my waist to heal my pain"* (p.10, YOE=5). Several participants reported subjective feelings of alleviation of pain, we do not claim that our prototype had any physical effects beyond subjective feeling. *"Usually when one sits for a long time the pain grows, but now on the second meditation* (i.e., the one with the object) *my pain disappears. I'm relating it to the object, since nothing changed between the two sessions, I'm sitting in the same place and the same position. The only differentiation I can think of is having the object or not having it, these are the facts."* (p.17, YOE=0).

Our findings contextualize the known effect of heat as a soothing, relaxing, or healing stimulus in the meditation domain. Within that context, targeted warmth's potential healing effect, either as a subjective feeling or with potential muscle-related pain relief, is extremely relevant as meditators experience physical pain throughout their practice, especially when practicing the classic sitting position. Future works should further examine that. Beyond meditation, targeted warmth can be a highly relevant domain for HCI innovation, in sports, physiotherapy, and the general population's back and neck pain.

6.2 Unpacking the tension between self-reliance and technology-supported process

Our participants discussed the unavoidable tension between an external technology and their internal introspection processes. They emphasized meditation as a self-reliant, unaided endeavor, with challenges and hardships that are at the core of the practice.

Indeed, prior work regarding meditation apps and VR technology reported on the negative aspects technology can introduce to such an introspective process, for example, it may distract meditators from being present in the moment without judgment, may introduce an achievement-oriented mindset, or may lead to over-reliant on technology [29, 30, 38]. Another negative aspect mentioned was meditation apps, that tend to focus on supporting relaxation, while meditation requires effort to enjoy the benefits of it [30].

We strived to address these challenges in our somaesthetic wearable design, using warmth as our only modality to minimize distractions and encourage multiple interpretations, designing for self-exploration, and utilizing materials that are appropriate for meditation.

Indeed, our findings show that our design was a successful first step in addressing the tension between technology and meditation. After the experience with our somaesthetic wearable, some participants suggested that technology can be a supporting aid if it is transitory rather than permanent, and some even went one step further and saw it as an appropriate support for meditation also over time, as it invites the meditator to challenge herself and explore new sensations. *"I would've thought that if you placed a technology that generated heat on me it would be distracting and bother me, another internal stimulus is the last thing one needs during meditation, but as soon as I felt it, I saw it did not add any distractions. The concept itself became interesting."* (p.14, YOE=1); *"I already feel somewhat experienced in meditation and my experiences feel quite consistent, and suddenly, an experience came that I was not familiar with. I don't know yet whether to associate it with a positive or negative valence, but I feel that it has opened interesting feelings for investigation for future meditations, and it intrigues me to keep the exploration of warmth sensations in the future"* (p.1, YOE=5);

In sum, our findings suggest that it is possible to "decrease the tension between technology and meditation" if the technology is designed as a tool that provides opportunities for meditators to develop a new relationship with the technology, appropriating it to their personal meditation technique, their preferred body location, their level of experience, and especially leveraging it to explore the immediate sensations and feelings they are having either a positive, negative, or neutral ones.

7 DESIGN GUIDELINES FOR TARGETED WARMTH TECHNOLOGY IN MEDITATION

Building on our design, implementation, and study findings, we propose the following design guidelines for targeted warmth wearables in the context of meditation, body awareness, or thermal interaction in general.

(1) **Design for self-exploration of feelings and emotions**: The wearable design and warmth technology should encourage self-exploration. The warmth temperature, thermal pattern, and attachment to body locations, should all be designed to afford straightforward adjustment with eyes closed, as different people experience warmth differently.
(2) **Encourage multiple interpretations of the warmth sensation**: We identified four potential roles for the warmth sensation during meditation- functional (pulling focal of attention), behavioral (motivating to "get back to the practice"), emotional (comforting during the lonely process), and therapeutic feelings. The design and provided instructions should not bias the user towards one role or another but encourage self-interpretation and meaning-making.
(3) **Choose materials that minimize physical and psychological distractions**: Meditators pay attention to their body

and mind for long periods, and every small detail is sensed, sparking physical or psychological reactions. Experienced meditators can handle it, but all meditators prefer to spend their practice time dealing with deeper sensations rather than superficial ones. If the wearable strap is tight rather than comfortable, if the material is too artificial rather than natural, or if the battery pack and digital technology are too visible rather than hidden, then the design adds superficial distractions that may occupy users' attention. It's best to make design decisions that minimize such distractions as much as possible.

(4) **Embrace the tension between self-reliance and technology-reliance**: Meditators constantly practice, striving to observe mental and bodily sensations as they are, without judgment or interpretation, in a self-reliance self-managed process. Adding technology to this introspective process creates an unavoidable tension between developing one's internal capacities vs. receiving assistance from an external device. Designers should address this unavoidable tension and make design choices that respect the self-reliant introspective process, encouraging users to use the technology as a tool that supports their process instead of compromising it, helping them to develop their internal capacities rather than replace their intrinsic effort. One such design choice was to limit ourselves to thermal modality only, as warmth can be sensed with eyes closed and is perceived as internal rather than external [57]. Another relevant design choice we took is the use of materials that are appropriate for the specific context, in our case, soft fabrics.

We hope our work can inspire HCI designers to leverage the vast potential of somaesthetic design for introspective processes in general, and meditation in particular.

8 LIMITATIONS

Our study has several limitations. First, there are many types of meditation practices, and different types of meditations can lead to different sensations and experiences and therefore to different findings. In our procedure we provided minimal guidance, to embrace both inexperienced and experienced meditators, and enable experienced ones to practice their own technique if they wish. Our qualitative analysis led to repeating themes about participants' interpretations of the warmth sensation, so even with a possible variance in meditation styles, common themes emerged. Future research should look more deeply into differences in warmth sensation interpretation across different types of meditation techniques.

Second, our findings are based on a single use of a novel technology, and as such are subject to the novelty effect. Specifically regarding the subjective interpretation of warmth sensation, prior work showed a tendency to associate warmth with positive and pleasurable feelings [12]. Our findings may be subject to such novelty effect, however, our participants reported a broad range of both positive, negative, and neutral interpretations. Future work should study the interpretation of targeted warmth sensation during meditation over time, to better understand the novelty effect as well as possible habituation. Another related limitation in repetitive or longer meditation sessions is possible sweating due to thermal hot spots [35].

Another limitation concerns our method. The two sessions participants performed in the study were meditation with and without the warmth technology, and we aimed to evaluate participants' experience with the technology and not without it, to uncover the subjective interpretations towards the targeted warmth. Our aim was not a comparison study between the two experiences, with and without the warmth. It would be valuable for future work to compare the differences between the two experiences, using mixed methods, to better understand the impact of the technology. Another possible limitation relates to the inherent limitations of qualitative interviews, which may be influenced by the interviewers' thoughts and expectations [49]. To minimize this risk, we followed a detailed protocol as well as increased the interviewers' awareness of this effect. Another possible limitation is the "good subject effect" [47] that may result in participants providing pleasing responses. To minimize this risk, we highlighted to the participants that there are no good or bad answers, everything they say or feel is valid and we want to understand their experience to the fullest, and that they should feel comfortable to also provide negative comments. Indeed the interview findings indicate a range of both positive and negative comments.

Finally, from a critical view perspective, it is important to mention that our work is inspired by the constructivism research approach by which we acknowledge that our subjective role as researchers is contextualized in our design work [55].

9 CONCLUSION

We presented a novel targeted warmth-producing wearable designed to support the delicate process of introspection during meditation. Our findings suggest that meditators with varied experience levels found the wearable appropriate for meditation practice, reporting that the targeted warmth sensation draws attention inward and strengthens self-exploration of feelings, emotions, and bodily sensations. We discuss the inherent tension between a self-reliant process like meditation and an external technology. In that context, our findings show that even when meditators started with a feeling that the effect of the warmth on their attention was too dominant and therefore distracting, eventually they used the technology to explore feelings and sensations that were not easily accessible without it and saw value in the technology as an appropriate support in their meditation practice. Our study revealed four potential roles for targeted warmth within the context of meditation: a functional role of grounding attention, a behavioral role of supporting and motivating, an emotional role of soothing and comforting, and a therapeutic feeling role in cases of pain. We provide design guidelines for targeted warmth technology in meditation and hope that our work, together with the existing body of work in somaesthetic design, may inspire HCI designers to create and study novel technologies that connect people more deeply with their body and mind, while not compromising the traditional knowledge, practice, and culture of introspection.

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